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Sympathetic sideband cooling of $^{171}Yb^+$ by $^{88}Sr^+$ for an optical atomic clock

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The frequency instability of single-ion optical clocks is fundamentally limited by the spectral resolution that is achieved in the excitation of the reference transition. The achievable resolution is typically limited by the coherence time of the light-atom-interaction. Excitation of highly forbidden reference transitions by ultra-stable lasers permits coherence times in the range of several seconds, so that comparisons between single-ion clocks with statistical uncertainty at the 10^{-18} level appear possible with averaging times of a few hours.

$^{171}Yb^+$ possesses an electric octupole (E3) transition at 467 nm with an excited state lifetime of several years. For second-long laser interrogation pulses, anomalous heating can limit the coherence between the ion and the laser even if it is cooled to its motional ground state initially, and the provided laser coherence time is sufficiently high. Direct laser cooling during spectroscopy is not possible with a single ion, but a co-trapped ion from a different species makes sympathetic cooling possible. Resolved sideband cooling on the clock transition of the ancillary ion removes thermal energy gained by the two-ion crystal during spectroscopy, if all relevant normal modes of the secular motion of the two-ion crystal are addressed.

We choose $^{88}Sr^+$ as our ancillary ion for two major reasons. The $^{88}Sr^+$ clock transition used for sideband cooling is close to the *magic wavelength* where the light shift of the $^{171}Yb^+$ E3 transition is zero. Consequently, the light shift induced by resolved sideband cooling is comparatively low. Secondly, a large contribution to the total uncertainty of the $^{171}Yb^+$ E3 transition stems from black-body radiation (BBR) of the ion environment. The sensitivity of $^{88}Sr^+$ to BBR is well known [2], so it can act as an in-situ sensor for the temperature of its environment, if additional shifts are suppressed [3]. The more accurately known temperature reduces the uncertainty of the BBR shift of the $^{171}Yb^+$ E3 transition. Additionally, the sensitivity of $^{171}Yb^+$ to BBR radiation can also be measured with greater accuracy, if the relative shift for both clock transitions is measured using a strong infrared laser field.

In preparation to the BBR measurements, we performed experiments with $^{171}Yb^+$ and $^{88}Sr^+$ in a linear segmented ion trap based on a stacked design of four printed circuit boards [4]. Doppler cooling and resolved sideband cooling for both species has been observed. The interplay between the Zeeman splitting of $^{88}Sr^+$ and its secular frequencies in the harmonic potential generated by the trapping field imposes limitations on the minimum duration of the sideband cooling pulses. We discuss both pulsed sideband cooling and continous sideband cooling and compare the final temperature, cooling time and ease of use. To find a good combination of cooling pulses on the first and second-order motional sidebands, we employ a simulation of the cooling process and anomalous as well as recoil heating [5]. Finally, we measure the heating rate of the different secular modes and find a large difference between the axial and radial secular modes. We attribute this difference to uncompensated micromotion along the trap axis caused by misalignment of the trap electrodes.

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